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SOME METEOROLOGICAL RELATIONSHIPS IN THE PREDICTION OF TORNADOES

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ABSTRACT

Synoptic surface and upper air features are analyzed in relation to tornado occurrences. The findings are incorporated into a forecasting system by means of which a preliminary alert forecast of tornado areas can be issued in the early morning hours for the period 1100–2300 CST. Basically, the forecast is derived through the prognostic locations of favorable surface parameters relative to the cold axis at 200 mb. In a test of the system on independent data, most of the multiple outbreaks of tornadoes are correctly predicted.

1. INTRODUCTION

This paper presents the results of an investigation by a group of Eastern Air Lines' meteorologists under the direction of J. J. George. The objective is to help develop a system by means of which a preliminary alert forecast of tornado areas can be issued in the early morning for up to 24 hours from data time.

The study was confined to the occurrence or non-occurrence of tornadoes and their general location during the period 1100–2300 CST. The timing of tornadoes from a pre-dawn forecast deadline appeared to be nearly an insuperable problem at this time.

Information on tornado occurrences during the years 1950 through 1955 was supplied by the Severe Local Storm Center at Kansas City. These valuable data were the foundation for the project, permitting full use of the researchers' time on synoptic study. The months of January through June for the years 1950 through 1955 were utilized in the following fashion: 1950 through 1954 formed the period of the dependent data, while 1955 data were retained for an independent test.

The entire approach to the problem was from the viewpoint of the forecaster, using charts and data that are usually available in the forecast office. Theoretical considerations played a part in defining the strategy of the attack, but the forecasting techniques given are completely empirical and were, without exception, dictated by the data.

The advent of tornado forecasting is undoubtedly one of the most ambitious ventures into operational weather prediction since the inception of the science of meteorology. The climatological expectancy of tornadoes and the probability of precise forecast verification is indeed so low, that for years a "Hands Off" policy was deemed the only proper manner to treat this weather phenomenon. However, an apparent increase in tornado activity and public demand during the middle and late 1940's, led to a change in this professional policy, and the creation of the Weather Bureau's Severe Local Storm Center (SELS), which is charged with the responsibility of providing adequate warning of severe local storms to the general public.

Tornado forecasting, still in its infancy, must be approached in the strictest sense of short-range prediction. Therefore, at the present time, operational forecasts are directed toward the period of maximum occurrence; i. e., afternoon and evening, and are issued on a 1- to 6-hour warning basis. Currently involved in the SELS operation

[1] Project sponsored by U. S. Weather Bureau.

is a forecast of a very general nature termed the "Convective Outlook." The convective outlook is issued by SELS at approximately 0500 CST, and in general terms outlines the forecast position which will likely be established in the form of a severe local storm warning later in the day. It is one of the purposes of this research to develop material which would include tornado activity in the convective outlook.

The tornado is one of the most complex and least understood mechanisms of meteorological phenomena, yet there is much we do know about the general meteorological environment in which these violent storms occur. For example, it is known that tornadoes occur in an airmass structure that is unstable. Since instability is an essential requirement for tornado activity, most of the current forecasting concepts involve a thermodynamic evaluation of hydrostatic instability based on predicted temperature and humidity values at various levels from the surface to 400 mb. A forecast of this nature is necessarily involved with the processes of horizontal advection, vertical motions, evaporation, and condensation. Therefore, forecasts of hydrostatic instability for periods in excess of 12 hours are subject to large error from a variety of sources.

Another commonly accepted qualitative conclusion is that most tornado outbreaks are favored in areas of warm, humid surface air near surface cyclones. In the presence of data which would support such a conclusion in a quantitative sense, one could draw the conclusion that an accurate prognosis of surface cyclones and surface moisture may well suffice as the initial vehicle with which to approach the longer-range forecast of airmass modification. The data in this research strongly suggest that the most powerful tool for the longer range severe weather forecast is an accurate prognostic surface chart relating to the placement and character of the surface cyclone and moisture pattern. This is indeed fortunate since, first, it represents an area of forecasting in which meteorologists are most experienced and therefore should be most proficient; second, it affords the use of a more compact data network allowing a better definition of parameters and patterns than procedures based principally on upper-air data. The intent of this discussion is not to deprecate the use of upper-air data in long-range tornado prediction. Indeed, an accurate prognosis of the surface patterns is dependent on the proper evaluation and prediction of dynamics involved in the lower and upper troposphere. However, the synoptic details relative to tornado occurrences are better defined and measured at the surface due to the frequency and density of the data.

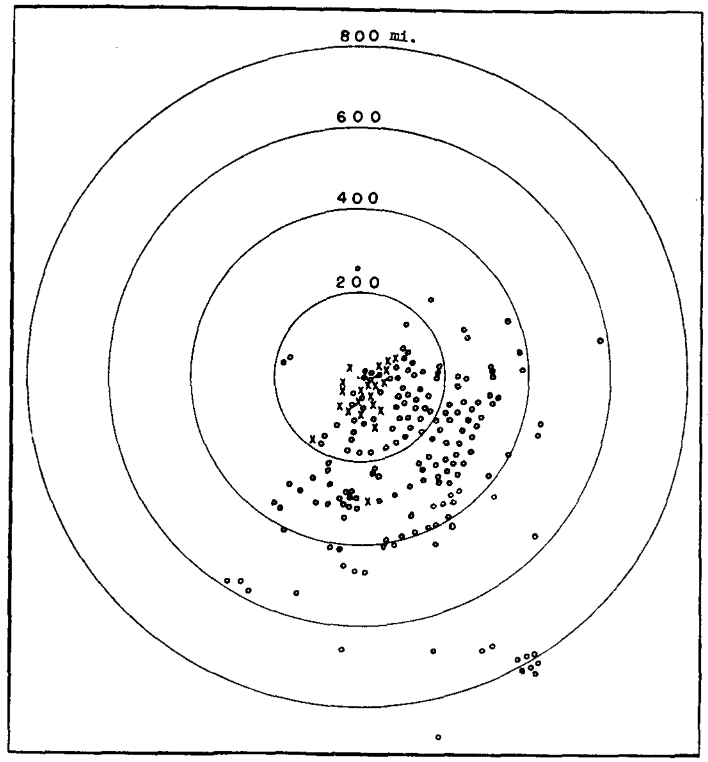

Figure 1.—Relationship of tornadoes to parent cyclone during January, February, and March, expressed in miles from cyclone center. North is at the top, east to right, etc. Circles are occurrences related to cyclones existing at 0030 CST. Crosses are occurrences related to cyclones which formed after 0030 CST; i. e., cyclogenesis.

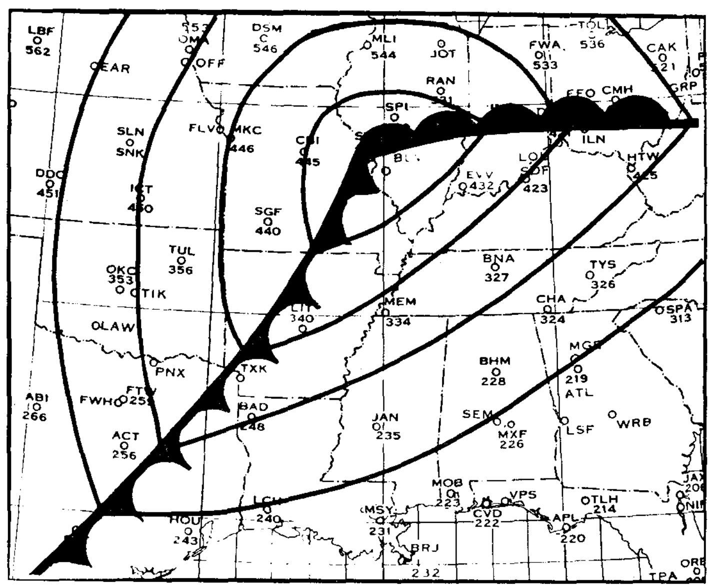

Figure 2.—A typical winter Low favorable for tornadoes in the southeastern quadrant.

2. SURFACE LOWS

Many researchers in the field of severe weather have noted that tornadoes occur in the southeastern quadrant of a wave cyclone, particularly if it is deepening. In attempting to define the validity of this qualitative conclusion, tornadoes over a 5-year period, 1950 through 1954, for the months January through June, were plotted by the month in relation to their parent cyclone at the time of occurrence. It was found that during January, February, and March, tornado activity was principally confined to the southeastern quadrant of the surface cyclone. However, beginning with April, a definite shift of tornado occurrences to the northeastern quadrant was

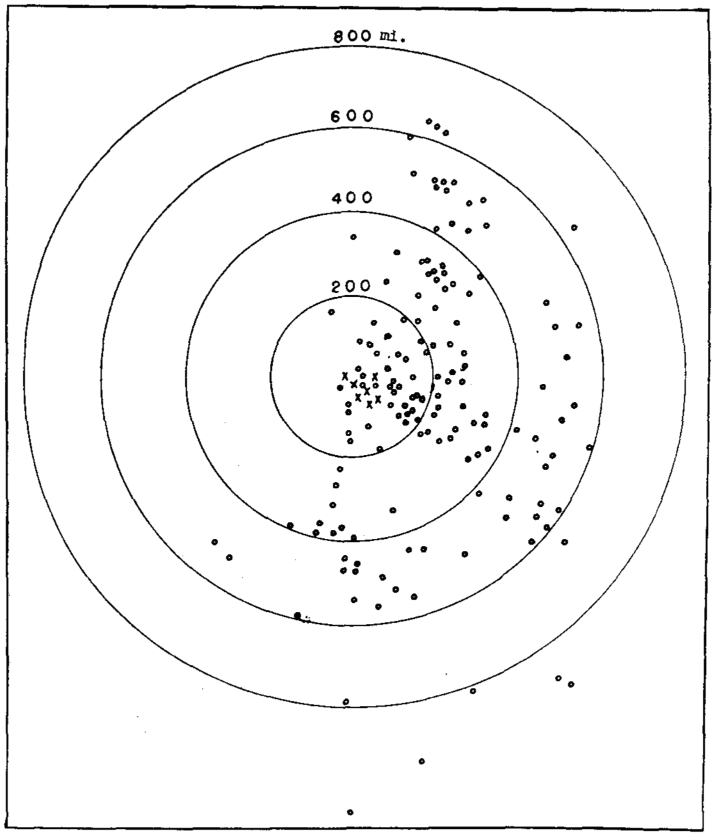

FIGURE 3.—Relationship of tornadoes to parent cyclone during April, expressed in miles from cyclone center. See figure 1 for explanation.

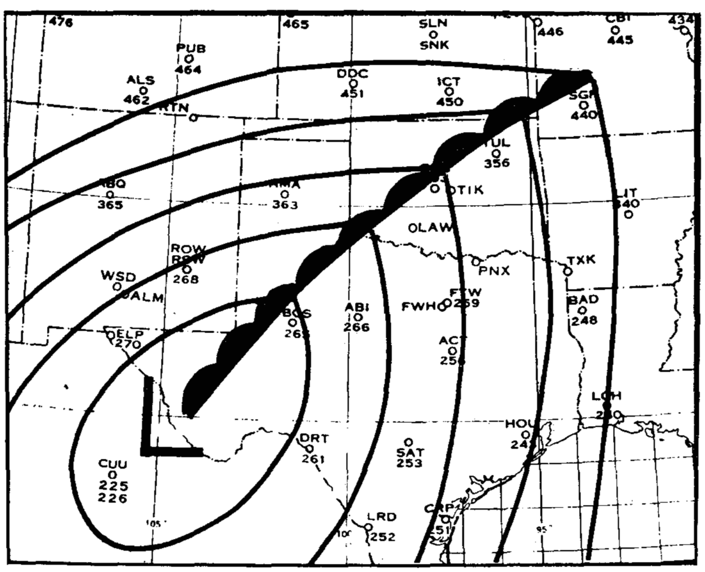

FIGURE 4.—A typical spring Low favorable for tornadoes in the northeastern quadrant.

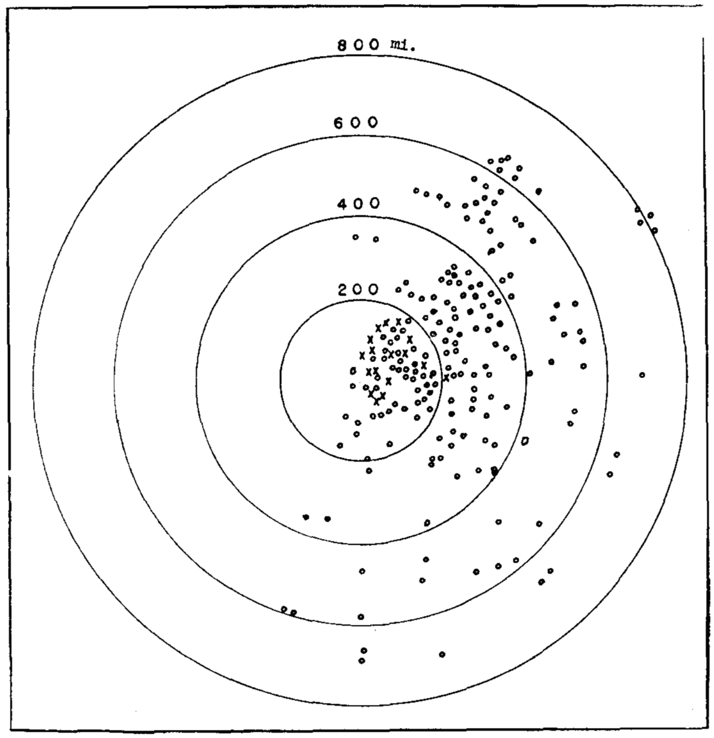

FIGURE 5.—Relationship of tornadoes to parent cyclone during May, expressed in miles from cyclone center. See figure 1 for explanation.

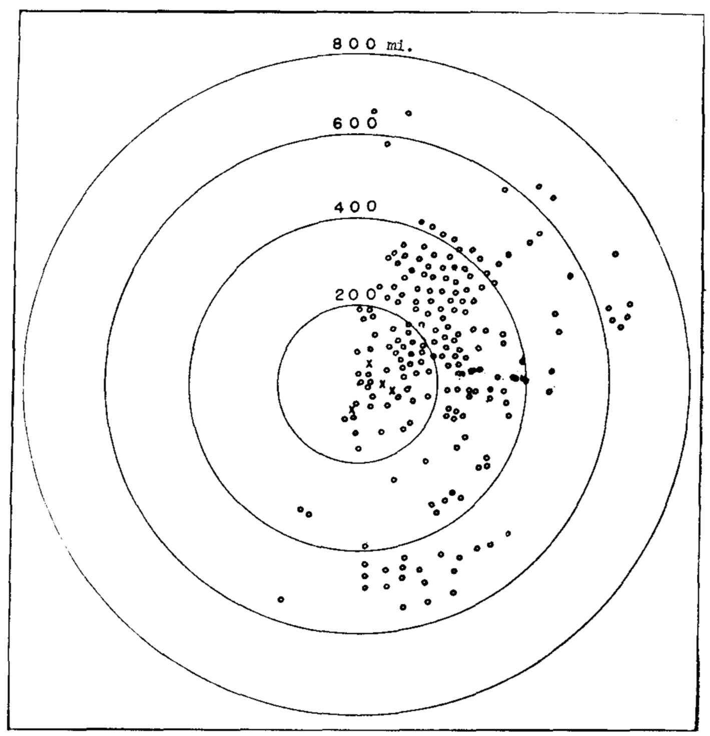

FIGURE 6.—Relationship of tornadoes to parent cyclone during June, expressed in miles from cyclone center. See figure 1 for explanation.

observed. In May and June, a positive maximum of tornadoes was found in the northeastern quadrant of surface cyclones.

Figure 1 is a plot of tornado occurrences relative to the surface cyclone for the months of January, February, and March. Most of the tornadoes are confined to a 450-mile radius in the southeastern quadrant. A significant group located about 700 to 800 miles south-southeast of the center was associated with very deep cyclones whose central pressures were less than 1000 mb. A few tornadoes

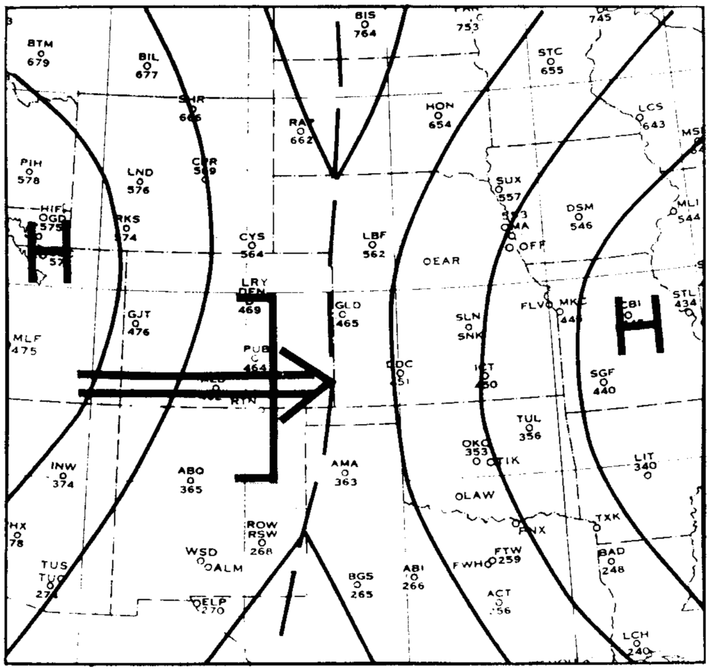

FIGURE 7.—A typical lee-side trough on an 0030 CST late spring chart. The bracket indicates west wind component over 25 knots at 500 mb., with the arrow through its mid-point indicating weak cyclogenesis expected in trough by 1830 CST.

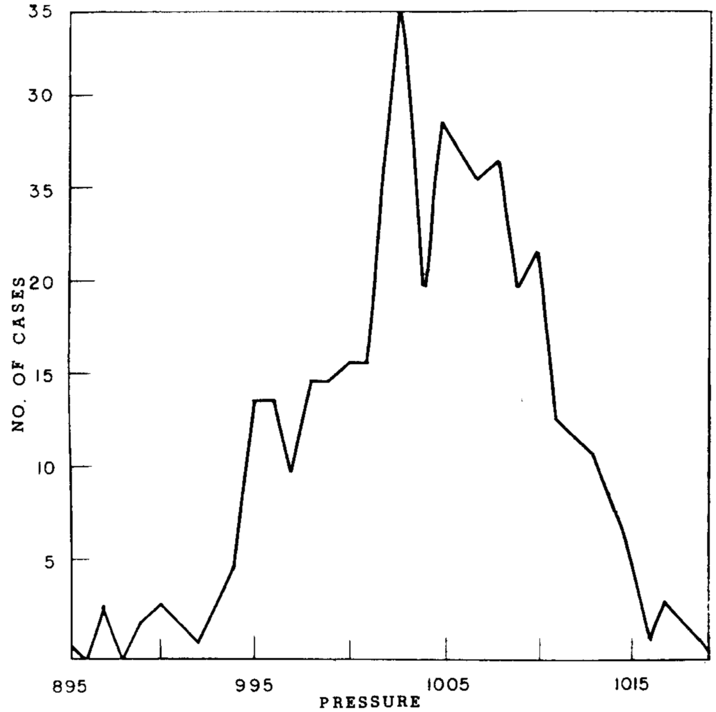

FIGURE 8.—Relationship of tornado occurrences to surface pressure at time of occurrence, interpolated to pressures between 6-hour synoptic charts with aid of reported pressure tendencies. Ordinate is number of cases, while abscissa shows pressure in millibars.

observed in the south-southwestern sector were associated with cold fronts, while the few in the east-northeastern sector were on warm fronts of shallow waves. Also clustered about the cyclone center are a number of tornadoes observed with the birth of a new cyclone during the forecast period, indicating the importance of a good cyclogenesis forecast [5, 6]. Figure 2 shows a typical winter Low favorable for tornadoes in the southwestern quadrant.

Figure 3, for April, shows the beginning of a trend toward tornadoes in the northeastern quadrant of Lows located mostly over Texas and Oklahoma. Figure 4 shows the typical synoptic pattern associated with tornadoes in the northeastern quadrant. Tornadoes in the southeastern quadrant are associated generally with cyclones located over the Midwest and South, with exceptions similar to those described for winter tornadoes.

In May and June, figures 5 and 6, the majority of the tornadoes occur in the Great Plains trough, usually in the northeastern quadrant of a Low located along the eastern side of the Rockies. They frequently occur along a stationary front out to a distance of 500 miles from the low center.

In the latter part of May and through June, a weak surface trough, often lying just east of the Rockies, is frequently the birthplace of weak cyclogenesis during the late afternoon. This presents a forecasting problem in that tornado areas are apparently linked to this particular development. A very simple method has been devised to predict and locate the area of such cyclogenesis. The leeward surface trough is, to a large extent, created by the mountain barrier effect combined with diurnal heating. Since diurnal heating is always involved, the only variable that needs to be considered is the degree and location of the maximum downslope area. This is done by locating the maximum zonal component of the westerlies at 500 and 700 mb. across the Rockies, as shown on figure 7. Weak cyclogenesis occurs immediately east of the mountains under the band of strongest west winds. About 25 knots was the minimum speed observed at 500 mb. associated with the formation of these weak depressions.

A general requirement for low pressure favoring tornadoes is shown in figure 8. It can be seen that only 5 percent of all tornadoes in this study were observed with a pressure higher than 1013 mb. on the surface chart.

Thus far the importance of surface cyclones and pressure values has been discussed. Equally important to the ultimate tornado forecast is the location of surface moisture relative to the cyclone location. Figure 9 is a graph of dewpoint associated with individual tornado outbreaks. The rapid increase in tornado frequency as the 60° F. dewpoint is approached suggests that this value may serve as a predictor. Figure 10 is a plot of tornado occurrences related to a typical 60° isodrosotherm. The cluster of activity near this line bears out the implications of figure 9.

An examination of the tornado cases in which the surface dewpoint was below 59° F. showed that they usually occurred within 250 miles of a low center of 1005 mb. or lower. The lower limit of the dewpoint in these cases was about 53°, although an occasional tornado was

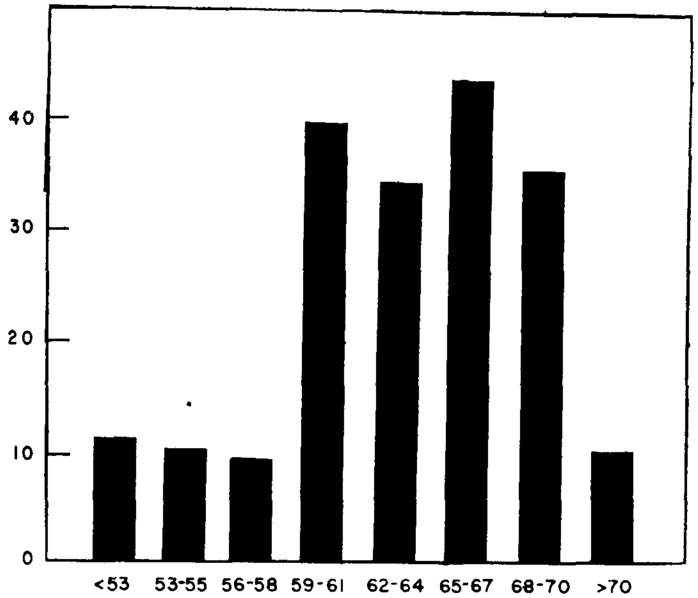

FIGURE 9.—Relationship of tornado occurrences to surface dewpoint at time of occurrence, interpolated between 6-hour surface charts whenever necessary. Ordinate is number of cases, while abscissa shows surface dewpoints in degrees F.

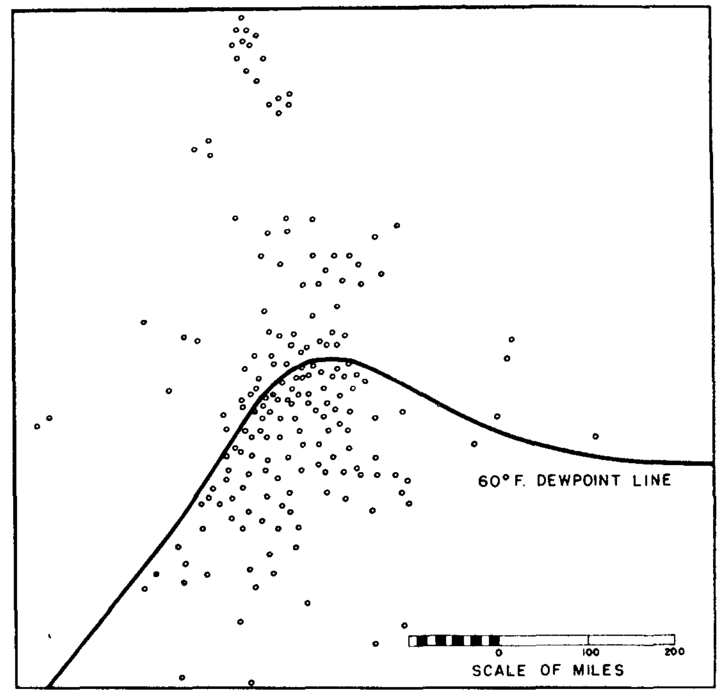

FIGURE 10.—Relationship of tornado occurrences to the surface 60° F. isodrosotherm during the months of January, February, and March.

observed near a deep low center with dewpoints in the upper forties.

The foregoing discussion emphasizes the importance of predicting the movement of surface moisture patterns. The displacement of surface moisture was found to be along the surface geostrophic wind and inversely proportional to the dewpoint gradient over a trajectory indicated by full advection of dewpoints with the geostrophic wind. Only two dewpoint lines were considered, the 53° and 60° isodrosotherms. All forecasts were made from the 0030 CST map and projected for 12 and 18 hours. Table 1 gives the percentage of geostrophic wind to be applied to various dewpoint gradients.

When a warm front crosses the predicted dewpoint trajectory, it was found that the projection of the dewpoint lines should be made in 6-hour increments. In most cases the warm sector is sufficiently moist to allow projection with 100 percent of the geostrophic wind to the warm front, then slowing abruptly to the speed of the warm front. In May and June, sufficient moisture is usually present ahead of the Low, even into the northeastern quadrant, so that the prognosis of dewpoint is seldom necessary.

3. STABILITY CONSIDERATIONS

The examination of thermodynamic diagrams has always seemed the most likely starting point for tornado forecasting, because of the extreme instability demonstrated by tornadoes and accompanying phenomena. Throughout the earlier stages of tornado research, a concept of a typical airmass structure involving a low-level inversion capping a moist layer surmounted with dry air, was considered a requirement for tornado outbreaks.

More recent investigations have raised some doubt as to what is to be considered a typical tornado sounding. Beebe [1] places emphasis on the increase in depth of the moisture layer just prior to the tornado occurrence and the destruction of the low-level inversion so often present well before the tornado outbreak. The method by which this change in vertical airmass structure takes place necessarily assumes an important role in the tornado forecast. Many soundings which were used in the original research were taken in the southern Great Plains area at 0900 CST. A sounding at this time of day reflects to a certain extent the results of nocturnal cooling in the lower atmosphere, since surface heating has not by this time progressed sufficiently to contribute materially to the destruction of the inversion through turbulent mixing. A proximity sounding in the same area taken at 1500 or 2100 CST would have the benefit of full insolation which could in some instances explain the principal process by which the airmass modification was effected. Other soundings may require a dynamic or advective element to produce the proper modification.

In an attempt to determine the factors which could change the lapse rate through the 850- to 500-mb. layer, several soundings were evaluated near the site and just

TABLE 1.—*Percent of geostrophic wind to be applied to various dewpoint gradients to project isodrosotherms*

Dewpoint gradient (from starting point to terminal point using 100 percent of geostrophic flow)	Percent of geostrophic wind
1 to 10 degrees	100
11 to 16 degrees	70
over 16 degrees	50

Table 2.—*Comparison between proximity and precedent tornado soundings*

Average lapse rate 850 to 500 mb., 24 hours prior to tornado occurrence		25.5° C.
Average lapse rate 850 to 500 mb., near time of tornado occurrence		28.0° C.
	Number cases	*Percent*
Increase in lapse rate 850 to 500 mb.; precedent to proximity	29	72.5
No change in lapse rate 850 to 500 mb.; precedent to proximity	2	5
Decrease in lapse rate 850 to 500 mb.; precedent to proximity	9	22.5
Warming at 850 mb.; precedent to proximity	28	70
No change at 850 mb.; precedent to proximiy	6	15
Cooling at 850 mb.; precedent to proximity	6	15
Warming at 500 mb.; precedent to proximity	15	37.5
No change at 500 mb.; precedent to proximity	14	35
Cooling at 500 mb.; precedent to proximity	11	27.5
Average temperature change 850 mb.; precedent to proximity		+2.7° C.
Average temperature change 500 mb.; precedent to proximity		+0.2° C.

before the time of a tornado occurrence. A comparison of these lapse rates was made with the lapse rates 24 hours previous in order to eliminate the diurnal influence. Final soundings were chosen within 100 miles and 2 hours of a tornado for 40 occurrences. This limitation is not as strict as that imposed by Beebe [1] in his study of proximity soundings. The data used here cannot in a strict sense qualify as proximity data. However, the general trend of warming or cooling at different levels should be significantly portrayed by the method. For the sake of convenience, the older data will be referred to as precedent data, and the data near the time and place of tornado occurrence as proximity data. Table 2 lists the pertinent comparisons between the proximity and precedent data studied in this report.

It is noted that in a number of cases the lapse rate between 850 and 500 mb. actually decreased just before the tornado outbreak. This can possibly be accounted for by the development of general cumulus activity and airmass saturation which would establish a moist adiabatic lapse rate over the area in question. Warming occurred at 850 mb. in more than 70 percent of the cases, with a few cases preceded by cooling. This cooling may be accounted for by vertical motion, evaporation, or advection. At 500 mb. there appears to be no significant trend, with the data evenly distributed among warming, cooling, and no change.

The general inference of this table suggests warming in the lower levels as the apparent cause of the increase in the lapse rate for the majority of cases.

4. 850-MB. LEVEL

From the surface data presented, it is apparent that an accurate forecast of the surface cyclone is essential to a successful tornado forecast. Equally important is the prognosis of deepening, filling, and cyclogenesis.

George [5] has demonstrated that an area of strong cold advection in the lower troposphere could be utilized as a predictor of cyclogenesis and deepening. This synoptic feature is best obtained at the 850-mb. level, although it is sometimes necessary to inspect the 700-mb. level when the 850-mb. trough is situated close to the Rocky Mountain chain. This parameter has been designated by George as a "Cold Injection", and is illustrated in figures 11 and 12.

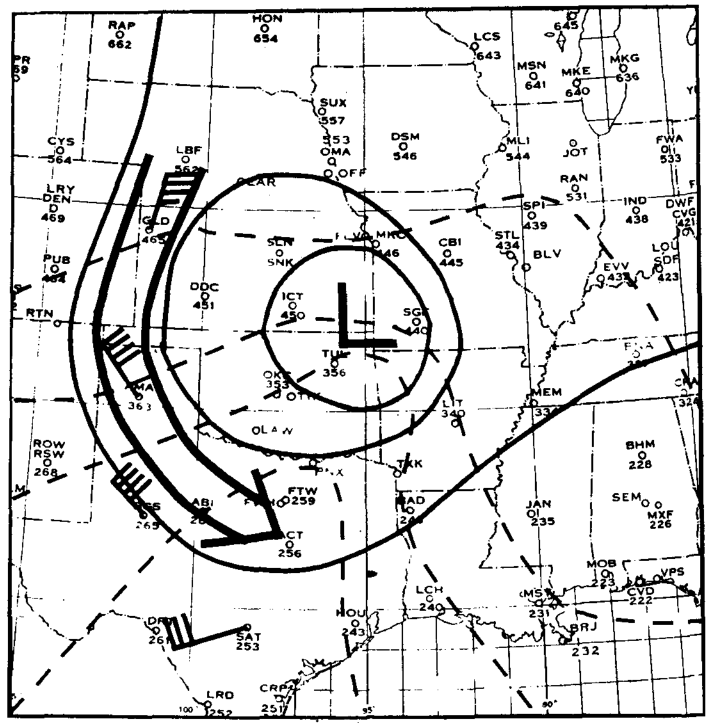

Figure 11.—A typical cold injection at the 850-mb. level (Dec. 5, 1954, 0300 gmt) prior to an outbreak of tornadoes in Alabama and Georgia. Dashed lines are 5° C. isotherms.

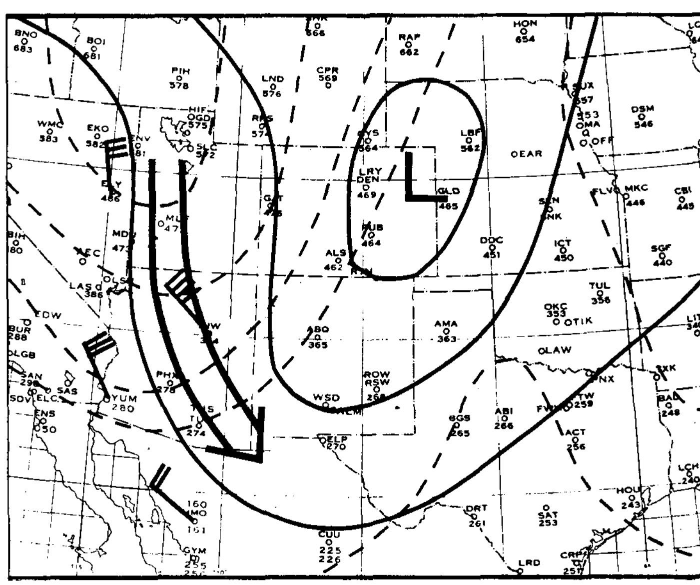

Figure 12.—A portion of the 700-mb. chart for February 19, 1954, 0300 gmt shows that a strong cold injection at 700-mb. level over the higher terrain of the Mountain States will often be as effective as an 850-mb. cold injection in the indication of a tornado day. In this illustration, numerous tornadoes were reported in Oklahoma the following afternoon.

The cold injection is *not* introduced as a prerequisite of tornadoes, but rather as a forecast tool in the preparation of the surface prognostic chart. It is significant to note, however, that the cold injection was present in 77 percent of the tornado situations in the winter and in 64 percent of the cases in the spring.

To the east of the 850-mb. trough, the observed winds usually display strong south wind components, usually 25 knots or more, forcing a temperature and moisture ridge northward over the tornado site by the time of occurrence. Unfortunately, this feature is often absent 18 to 24 hours prior to occurrence of the tornadoes. Due to the up-welling of moisture from lower levels, evaporational cooling, and vertical motions, satisfactory prognosis of the temperature and moisture ridge for periods longer than 6 hours is extremely difficult. Much greater success was attained if this forecast was confined to the surface data.

5. 500-MB. LEVEL

Since the 500-mb. chart is the most complete and quickly available of the higher-level charts, the most intense study was made at this level. The outstanding features of this level near tornado time were taken from composite charts, after Beebe [2]:

1. The presence of a large trough west of the tornado area.
2. Winds averaging 50 knots over and to the north of the tornado area.
3. Practically no thermal advection.

A series of composite charts drawn from the charts available at forecast time (2100 CST in most cases) for several early season multiple tornado outbreaks showed some distinct features:

1. An isotherm ridge over the future tornado zone.
2. A difluent contour pattern from the trough to the eastern ridge.
3. A definite jet maximum in the trough west or southwest of the forecast tornadoes.
4. A $-15°$ C. isotherm through the tornado area.

It was found that composite charts obscured such a variety of individual 500-mb. patterns that they became nearly useless as tornado predictors. For example, winds as low as 25 knots, temperature ranging from $-5°$ to $-22°$ C., and completely straight flow more than 1,000 miles west or southwest of the tornadoes were observed. Some cases showed nearly parallel flow from 850 to 500 mb.

Individual predictors at this level were analyzed in detail, and although each one added confidence to the tornado forecast, no single one, nor combinations of two or three seemed to hold up for more than one season:

(1) The isotherm ridge east of the trough during the years of 1953 and 1954 forecast the longitude of the tornadoes within 3° about 84 percent of the time, but failed in other years when many cases of straight contours and isotherms at 500 mb. accompanied tornadoes.

(2) The deepening or filling of a trough from forecast time to tornado time invalidated an attempt to fix the latitude of the tornado by the latitude of the isotach maximum and the vorticity maximum in the trough.

(3) Because tornadoes frequently occur along certain

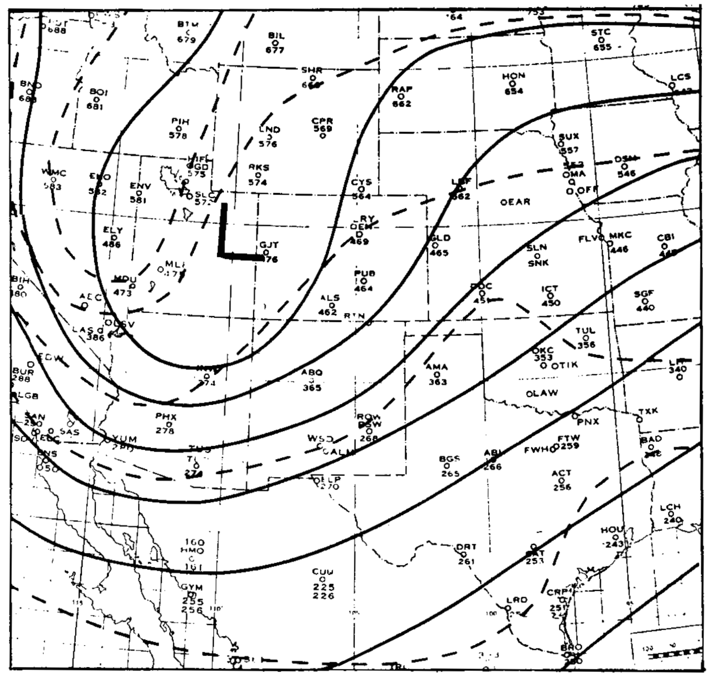

FIGURE 13.—A typical 500-mb. chart (Feb. 19, 1953, 0300 GMT) preceding tornado outbreaks over the Great Plains during the following afternoon. The isotherm ridge over the Plains, as in this case, was often a good predictor of the longitude of the expected tornadoes.

isotherms, they were averaged and tabulated by months, as shown in table 3, but again natural variability was so great as to render this useless as a forecasting parameter.

(4) Fast-moving shallow troughs were quite accurate predictors, when available. The tornadoes occurred about 350 to 400 miles ahead of the trough line with favorable surface conditions present, and about due east of the isotach maximum in the trough.

(5) The forecast position (at times difficult) of the southern edge of the 50-knot wind stream at 500 mb. over a favorable surface area was often helpful for latitude determination of tornadoes.

(6) Cold Lows at 500 mb. moving east from the southern Rockies [4] were often producers of extensive severe weather and multiple tornado situations.

(7) The rather surprising frequency of tornadoes under straight flow at 500 mb. made all of the previous 6 forecasting aids unusable during these conditions. The only help in these cases seemed to be the intersection of a 50-knot wind zone with favorable 850-mb. and surface predictors.

TABLE 3.—*The average isotherm at 500 mb. over future tornado location*

Month	Average Isotherm (° C.)
January	−15
February	−15
March	−14
April	−13
May	−11.5
June	−9.5

6. 300-MB. LEVEL

An excellent and detailed paper by Ramaswamy [8] on severe local weather in India bridged many of the gaps between theory and daily forecasting. His 300-mb. patterns for severe weather applied quite well for many situations in the United States, but the strong frontal and low pressure systems causing severe weather in this country had no counterpart in India. There were many tornado situations present when Ramaswamy's patterns were negative. However, his difluent trough pattern, similar to figure 13, for 500 mb. was pronounced in some of the most severe late-season cases in the United States. The devastating series of June 7 and 8, 1953 are good examples.

A study by Porter and others [7] of squall lines was checked for tornado clues, and some patterns were noted at 300 mb. with similar configurations to the 500-mb. patterns detailed previously. However, the southern edge of the 50-knot wind zone at 500 mb. was found to be under the edge of a 70- to 80-knot zone at 300 mb. over a large number of tornadoes, particularly of the multiple variety. Also, the forward right quadrant of an isotach maximum in the main jet stream was a favorable location, although this finding was not usable when projected for an 18-hour forecast.

7. 200-MB. LEVEL

A feature of the 200-mb. level which consistently located the site of subsequent tornado outbreaks was the axis of the cold tongue. This relationship was noted during the study of the developmental data when the cold tongue was related to tornado areas. During the test year of 1955, individual tornadoes occurring between the hours of 1100 and 2300 CST were plotted relative to the axis of the 200-mb. cold tongue as delineated by the 2100 CST data of the previous evening. This distance from the tornado site to the cold axis was measured in degrees of latitude and the results are tabulated in table 4.

From this table it is noted that 74 percent of the tornadoes occurred within 2° of latitude of the cold axis. It is emphasized that this is not a synoptic measurement, as the tornadoes occurred 14 to 26 hours after the time of the data used to define this parameter. No specific values seemed to be required, although in the majority of the cases the temperature along the cold axis was −60° C. or colder. This figure agrees closely with the findings of Galway and Lee [3] of the SELS Center. They related tornado occurrence to a jet intersection at 200 mb. with the southwestern quadrant of the cold pool as outlined by the −60° C. isotherm. They describe this pattern as a simultaneous relationship to the tornado occurrence. In this research, however, the axis of the cold tongue is presented as a predictor valid for time periods up to 26 hours from data time.

TABLE 4.—*Frequency of distances of tornado sites from 200-mb. cold tongue of previous evening*

	Tornado distance from cold axis (° lat.)				
	0	1	2	3	Over 3
Number of cases	100	74	62	37	47
Percent of cases	31	23	20	11	15

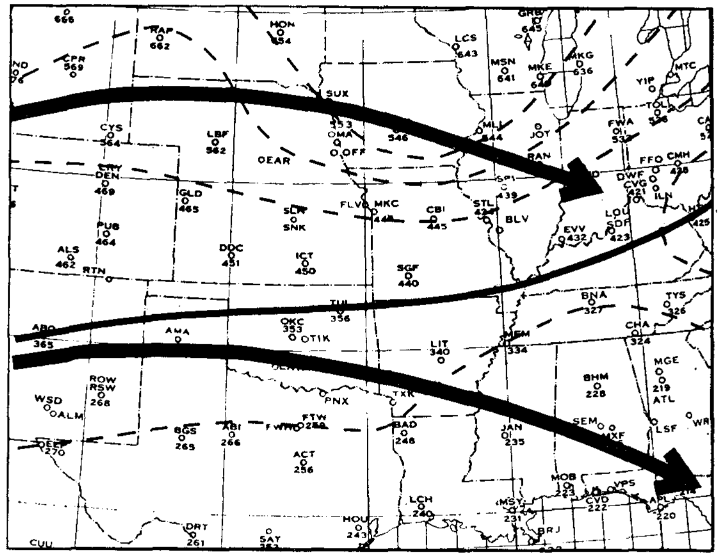

FIGURE 14.—An illustration of the axis of a cold pool at 200 mb. lying between two jet streams. Thin solid line is axis of cold tongue while heavy lines show jet streams. Thin dashed lines are isotherms at 2° C. intervals.

8. FORMULATION OF THE FORECAST

Basically the forecast is derived through the location of favorable surface parameters relative to the cold axis at 200 mb. From a forecasting standpoint this requires a surface prognostic chart for locating the low center and moisture pattern expected 12, 18, and 24 hours after the 0030 CST surface map available at forecast time, along with the 200-mb. cold axis delineated by isotherms drawn for 2° intervals at 2100 CST of the previous evening. Often there is a cold axis parallel to, and between, two jet streams as in figure 14. At times, however, branches of the cold axis appear, and these should be considered also, as in figure 15.

The forecast can be made in the following steps during January, February, and March (see fig. 16):

1. Prognosticate position of surface cyclone and fronts for 1230, 1830, and 0030 CST.
2. Prognosticate 60° F. dewpoint lines for each prognostic chart.
3. From prognostic low center draw a 450-mile radius from cold front to warm front through warm sector.
4. Outline 60° F. dewpoint area within above radius.
5. Eliminate prognostic pressure areas expected to be above 1013 mb. within above radius.
6. Plot 200-mb. cold axis on surface prognostic charts.
7. Designate alert area as that portion of favorable surface area intersected by 200-mb. cold axis, including a 2° latitude strip on either side of the axis within the surface area.

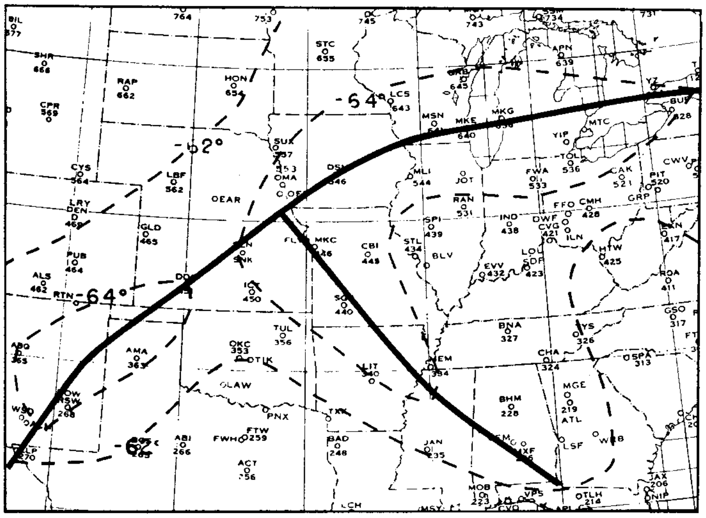

FIGURE 15.—An illustration of the axis of a cold pool at 200 mb. with a branch extending into the Gulf States.

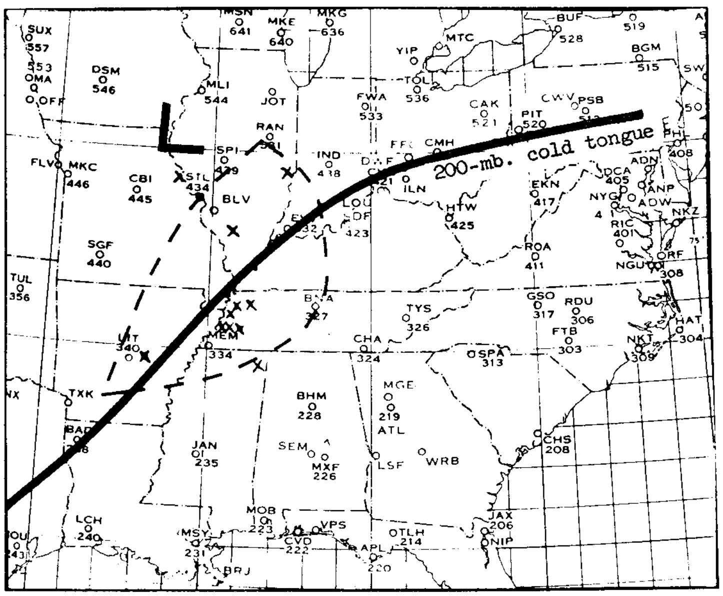

FIGURE 16.—A typical tornado alert area for a winter month, outlined by the dashed line. The area is bounded on the west by the prognostic position of the cold front for 1830 CST, on the south by a 450-mile radius from the prognostic low center, and on the northeast by the prognostic 60° F. isodrosotherm. The 200-mb. cold axis is the actual position from the 2100 CST chart of the previous evening. Tornado occurrences are located with small crosses.

8. Exceptions to steps 2 and 4: If the low center pressure is less than 1005 mb., the dewpoint is in the 53° to 59° F. range, *and* a 60° F. dewpoint is within 450 miles of the low center, a favorable surface area lies in the warm sector within a 250-mile radius of the low center.

The favorable surface area indicated on the 1230 CST prognostic chart may come under the 200-mb. cold axis, and an alert should begin at 1230 CST. However, if the favorable surface area does not reach a 200-mb. cold axis until 1830 CST, the alert should be delayed until that time.

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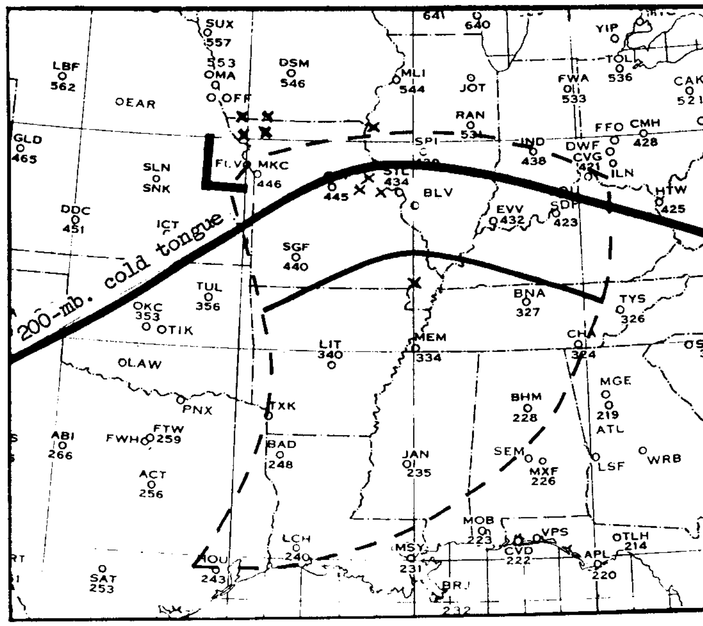

FIGURE 17.—A typical tornado alert area for April, outlined by the dashed line. The area is bounded on the west by the prognostic position of the cold front for 1830 CST, on the south by a line 2° of latitude from the 200-mb. cold axis, on the east by a 550-mile radius from prognostic low center, and on the north by the prognostic position of a warm front. Tornadoes are indicated with small crosses.

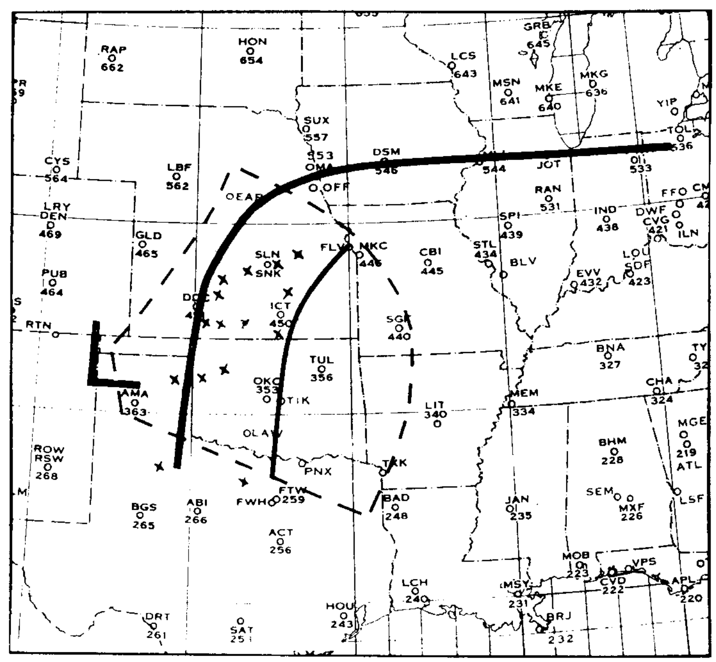

FIGURE 18.—A typical tornado alert area for a weak or moderate Low in May and June, outlined by the dashed line. The area is bounded on the west and northwest by prognostic frontal positions, on the northeast and south by distance limitations (see text) from prognostic low center, and on the east by a line 2° of latitude from the 200-mb. cold axis. Tornadoes are indicated with small crosses.

The forecaster's judgement should be used for appropriate timing by these considerations during the entire period from 1230 until 0030 CST.

During April, the same general procedure can be used, but a larger radius from the low center should be used—about 550 miles. It can be extended into the northeastern quadrant if frontal, moisture, and pressure factors are favorable. See figure 17.

In May and June, the boundary for a favorable tornado area begins about 100 miles south of the prognostic low center, extends 500 miles east-southeast and thence northward to any front in the northeastern sector, as in figure 18. Timing in these months should be from the 1830 CST prognostic chart, as climatology and slow-moving pressure systems favor a maximum of late afternoon tornadoes over the Great Plains. However, if an active Low is moving across the Central States or the Great Lakes region, the early-season rules can be applied throughout, including a southward-extending radius of about 500 miles from the prognostic surface Low.

9. RESULTS OF INDEPENDENT TEST YEAR

A forecast was made for each day of the test period, January through June 1955. These test forecasts were based upon 0030 CST surface maps plus the 2100 CST 200-mb. charts, and were valid for 1830 CST. An alert area was outlined if *all* of the conditions specified in section 8 were met. Obviously, if they were not met, no area was outlined and the test forecast was for no tornadoes.

Tornado occurrences between 1100 and 2300 CST were used for verification, and these data were obtained from maps of tornado tracks prepared in the SELS Center. (These maps were prepared from data published by the Weather Bureau's Office of Climatology.) Tornadoes occurring west of the Rockies, waterspouts, and funnels were not considered in this verification.

There were 181 days during this period, and there were tornado forecast areas at 1830 CST on 55 days. Of these 55 forecasts, 39 were verified by one of more tornadoes occurring within the area during the valid time (1100–2300 CST), 9 areas were near-hits (tornadoes within 140 miles), and no tornadoes were reported in or near 7 of the areas. It is important to note that a forecast was made on only 7 days when no tornadoes were reported. Some of these 7 days included severe hail situations. There were 34 days during which tornadoes occurred during the valid time but for which no forecast area was made. Most of these were isolated tornadoes, and only 6 of these 34 days had more than one tornado. Thus, most of the multiple outbreaks were correctly predicted, although there may have been some error in location because of slight errors in the surface prognostic chart.

TABLE 5.—*Results of forecasting test on independent data, January–June, 1955*

	Forecast	Observed	Percent
Tornado days	48	82	59
Tornado areas	55	39	71
No tornado days	126	99	79
Individual tornadoes	180	335	54

A test on individual tornadoes, 335 cases, showed that 180 tornadoes were correctly placed in the forecast area. Another 60 occurred outside the forecast area, while 95 appeared on negative forecast days. Table 5 presents the forecasting record for January through June 1955.

10. CONCLUSIONS

With the material presented in this report it is apparently possible during the early morning hours to issue successful forecasts of afternoon and evening tornadoes. The forecasts, however, are quite general in nature relative to timing and the size of the alert area, and therefore would serve best as a preliminary alert which could be refined with later data in reducing the size of the area and the valid time interval.

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